Le projet Hydre : Echantillonnage 2D des vitesses et des concentrations en collecteur d'assainissement

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The Hydre project: 2D sampling of velocities and concentrations in sewer channels

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ABSTRACT

Regulatory specifications and technical obligations require extensive knowledge of how sewer networks actually operate. This knowledge entails an understanding of both hydraulics and pollutant transport mechanisms; it also depends on the capacity of a given measurement point to yield a set of representative results and implies defining criteria that facilitate the choice of potential measurement sites. To proceed with the definition of such parameters, a measurement site qualification methodology, based on a generic model, is being developed, an effort that has necessitated deriving an experimental data set in order to validate the modeling layout. This article will present a velocity and concentration field sampler, designed, developed and implemented for the purpose of acquiring these field data, in addition to discussing the results obtained.

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RÉSUMÉ

Les prescriptions réglementaires et les impératifs techniques nécessitent une bonne connaissance du fonctionnement réel des réseaux d'assainissement. Cette connaissance passe par celle de l'hydraulique d'une part, et par celle des polluants transportés d'autre part. Elle dépend de la capacité d'un point de mesure à donner des résultats représentatifs, et nécessite la définition de critères facilitant le choix de sites de mesure potentiels. Afin de définir ces paramètres, une méthodologie de qualification des sites de mesures fondée sur une modélisation générique est en cours de développement. Cela nécessite des données expérimentales pour valider la modélisation. Cet article présente un échantillonneur des champs de vitesses et de concentrations conçu, développé et utilisé pour acquérir ces données de terrain ainsi que les résultats qui ont été obtenus.

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INTRODUCTION

One of the keys to water resource management for the cities of today and tomorrow **[1]** relates to sewer networks. The operations of these networks often diverge quite substantially from the set of hypotheses adopted during the design stage, which has led to reliance on *in situ* measurements to better comprehend, and then improve, the state of sewer network operations. This step becomes much more rational within a system of continuous monitoring. Moreover, a regulatory context dictated by inter-Ministerial decree, adopted on December 22, 1994, together with a framework provided by French Standards NF EN 752-2, NF EN 752-7 and NF P 15-900-2 **[2-4]**, now requires service operators to oversee their networks with even greater attention to detail, in addition to evaluating performance, intervening quickly in the event of non-systematic malfunctions and informing the facility owner of improvements likely to enhance performance, all in the aim of increasing sewer collection reliability. Even though sensor use has become widespread, this practice is currently challenged by the lack of sites meeting applicable hydrometry standards and safety requirements for both personnel and equipment **[5]**.

In seeking to reconcile measurement quality with practical constraints, a measurement site qualification methodology is currently being developed **[6]** to enable:

- qualifying measurement sites;
- defining installation procedures applicable to a given sensor;
- specifying the protocol for interpreting sensor results, making it possible to convert the set of measured values to the intended physical magnitudes;
- quantifying the level of precision inherent in data provided by existing sites.

This work program comprises an experimental phase whose purpose is to validate the models used in the methodology. It was decided to perform measurements *in situ* for two reasons: the techniques derived for research needs may serve subsequent actual applications; and the phenomena due to network configurations are numerous, yet their representation in laboratory testing is still not very well controlled.

This article will discuss the methodological design and results obtained using a mechanical device for exploring the cross-section of collector channel flow. Such a device can be used for a wide range of hydraulic contexts (including high filling rates), thereby enabling the implementation of various velocity sensors as well as systems for extracting effluent samples.

THE HYDRE SET-UP

Larrarte and Cottineau **[7]** have already presented two samplers for studying velocity fields and suspended matter concentration fields. They demonstrated that a single-point sampler was indeed capable of yielding a value representative of the average concentration within a large sewer channel where velocities exceed 0.6 $m \cdot s^{-1}$, i.e. equal to the auto-flushing drainage rate. They also faced the constraint that neither velocity nor concentration could be measured over a short time period since one sampler had to be disassembled before using the other; moreover, measurements could not be conducted above the channel bank. A new set-up, called Hydre[1], was developed to overcome the limitations imposed by the previous systems.

Its objective is to perform measurements within a sewer channel, regardless of meteorological conditions, in particular during rainy weather, while access to the channel interior is blocked and only the manhole (whose diameter is currently 0.6 m) enables introducing or removing objects. In addition, safety constraints necessitate a low-voltage power supply (less than or equal to 24 V) and impose that system elements permanently installed inside the channel may not, under any circumstances, obstruct or impede flow.

In light of past experience acquired **[7]**, the design produced was intended to meet the following specifications:

– measuring velocities locally with a respective step of 0.10 m along the vertical (at between 0.10 m and 1.50 m from the base plate) and 0.20 m along the transversal;
– quantifying suspended matter concentrations.

The photograph in **Figure 1** shows Hydre in a configuration for conducting measurements. This set-up is composed of a horizontal rail permanently installed inside the sewer and a self-propelled cart equipped with a jack-activated vertical exploration system. The positioning step is performed using

[1] *The name Hydre was given out of reference to Hydre de Lerne from Greek mythology, the creature killed by Heracles, who also killed the brother Cerberus, the Guardian of Hell. Cerberus the sampler was a figure with three-headed measures named after the three-headed dog and was introduced following the project called Orpheus. This legendary Greek poet, son of the muse Calliope, married the nymph Eurydice, but the young woman died from a snake bite. Carrying her lyre, Orpheus tamed the ferocious dog Cerberus, Guardian of Hell.*

displacement sensors placed on each axis. During the installation step, the mobile part is positioned and guided along the manhole in order to drop onto the horizontal rail without requiring a utility agent to actually enter the sewer. A jack locks this part on the rail, and the system can then switch to the measurement phase. The measurement head **(Figure 2)** is fastened onto the vertical support and is fitted with two velocity measurement sensors and an extraction nozzle. In order to avoid clogging of the head parts, blowing nozzles have been installed near each velocity sensor; furthermore, the extraction hose is cleaned with compressed air before each sampling.

The velocity measurement is performed using two PVM-PD Doppler current meters. During previous experimental work conducted by the authors, these sensors were found to be most satisfactory.

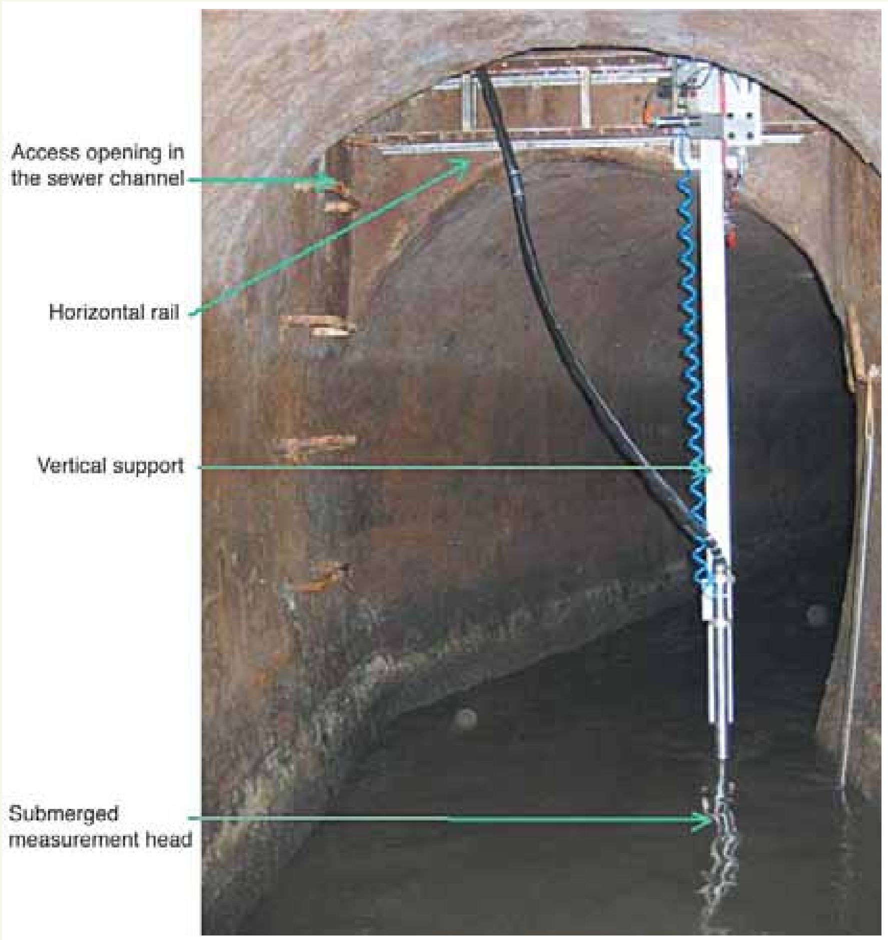


Figure 1
The Hydre configuration during the measurement campaign

These current meters have the advantage of offering either instantaneous measurements or average measurements over an adjustable time interval, yet as a disadvantage the acquisition stage cannot be automated and needs to be triggered manually.

The guiding step takes place from the surface, where a carriage has been fitted with a bottling system, two velocity measurement boxes and various equipment required for the assembly to operate appropriately **(Figure 3)**. Data acquisition and control rely to a great extent on offset input and output devices connected by an RS485 type of series interface. This layout also makes it possible to limit the cabling placed in the sewer line. A software program written for the LabVIEW environment produces the measurement sequences according to a matrix of target points defined in a file created beforehand. Once the target point has been reached, the velocity measurement is initiated by the assigned operator. Should the operator so desire, an effluent sampling sequence can be performed thereafter.

Figure 2
Detail of the measurement head

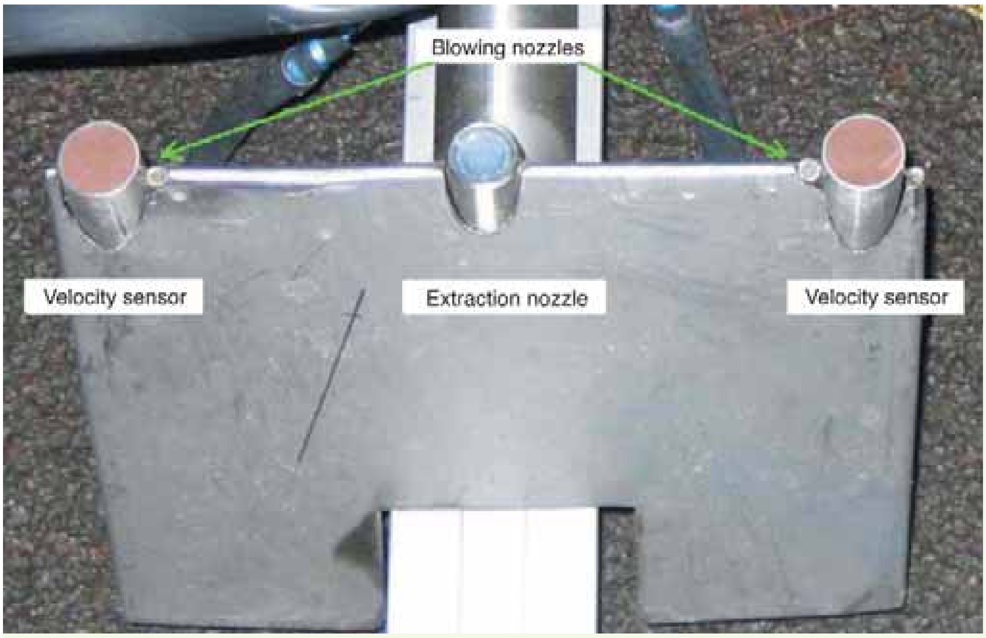
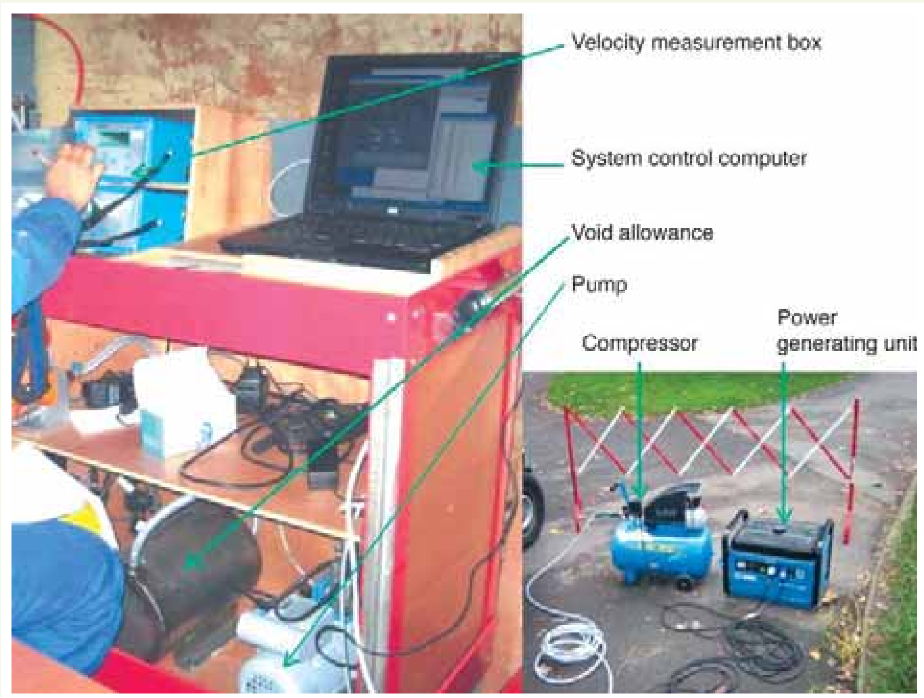


Figure 3
System control station



In order to characterize pollutant flows, suspended matter concentrations are determined based on effluent samples extracted using a 0.01-m internal diameter hose, which complies with Standard ISO 5667-10 **[8]**. Samples are extracted one at a time; this automatic sequence begins by closing the bottle with the suction head, then proceeds by a blow cleaning of the suction hose. Afterwards, vacuum extraction is activated and the bottle is filled until reaching the level of a detector. The suction head is then raised and the bottle may be removed by the sampling operator. At the same time, the measurement head immediately moves to the subsequent target point listed in the file. Out of concern for safety, a fairing is placed on the device **(Figure 4)** to avoid projections of broken glass in the case a bottle bursts, as was experienced during testing. **Figure 5** shows the user interface.

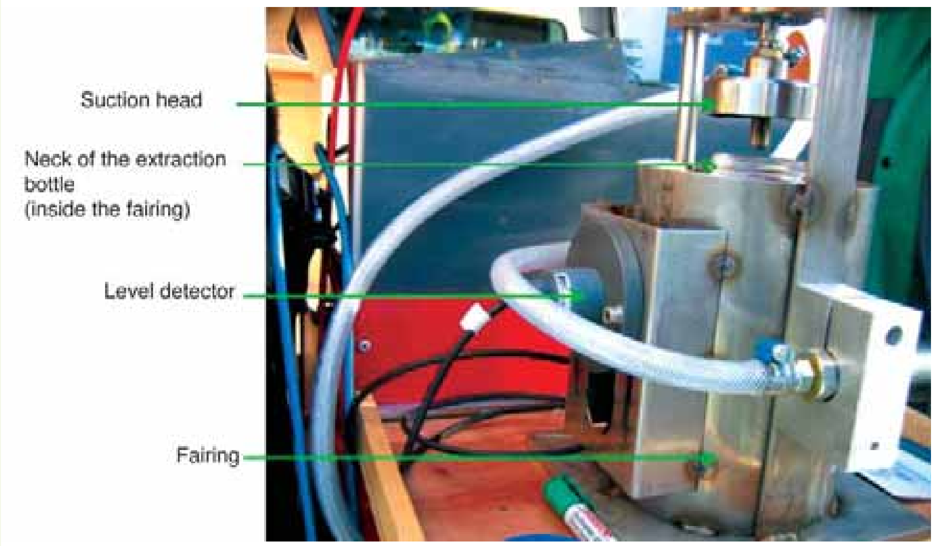


Figure 4
Bottle and fairing on the vacuum suction set-up

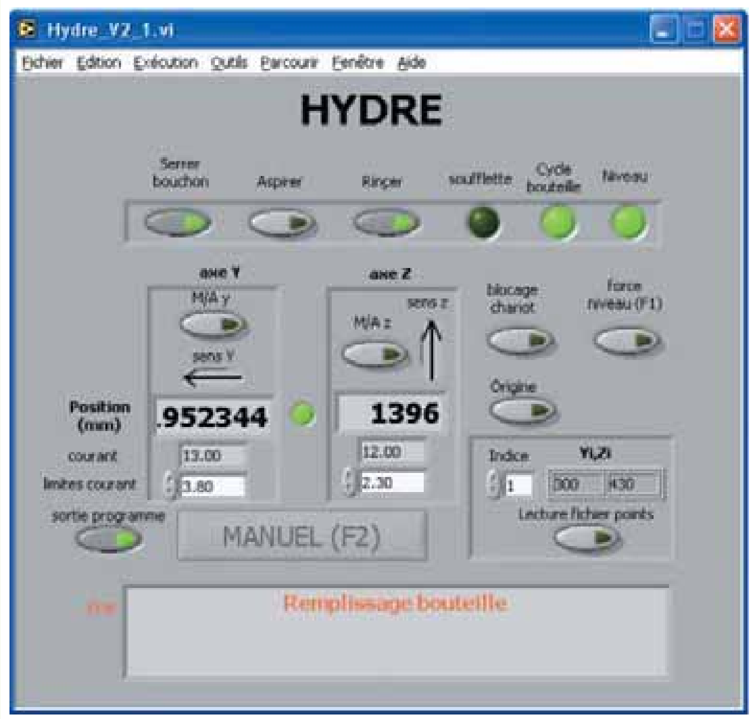


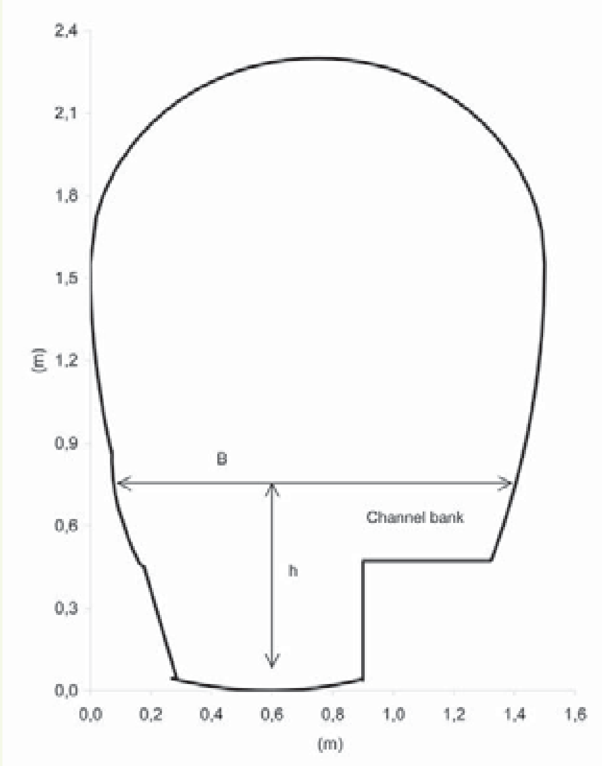
Figure 5
Software user interface

EXPERIMENTAL SITE

To better understand the velocity and concentration fields inside urban sewer channels and in light of the research already carried out **[7]** on a site within the Nantes Metropolitan sewer network, it was decided to focus on an experimental site featuring lower water velocities.

The so-called *Jardin des Plantes* measurement site is located in an egg-shaped channel with a bank that makes up part of the combined sewer network. The transverse channel section **(Figure 6)** has a maximum height D equal to 2.30 m, while h is the water height and B the free surface width. The maximum width y_{max} equal to 1.50 m is associated with a channel height z_{max} also equal to 1.50 m. The channel is made of high-quality concrete with a Manning-Strickler coefficient estimated at 70 $m^{1/3}s^{-1}$. The channel bank consists of a horizontal step 0.40 m wide located to the right when looking upstream. The width of this bank takes up 27% of the maximum channel width. Moreover, a temporary deposit was observed at the level of the channel base plate.

Figure 6
Geometry of the sewer cross-section in the Jardin des Plantes area. View looking upstream



This site has not been fitted with continuous measurement devices, though the Nantes Metropolitan Wastewater Authority operates a measurement site (called *Duchesse Anne*), located 600 m downstream. Just three smaller lines are connected to the channel between the *Duchesse Anne* and *Jardin des Plantes* sites. Their local contributions were deemed negligible compared to the effluent from 150,000 population equivalents flowing into the *Duchesse Anne* point. By using continuous measurement data, the deciles of height measured during dry weather and the associated velocities **(Table 1)** could be determined. These findings reveal that the ratio of the median (or 5th decile) of water height to the maximum channel vertical dimension *D* equals 0.30 during dry weather conditions.

Table 1
Site characteristics

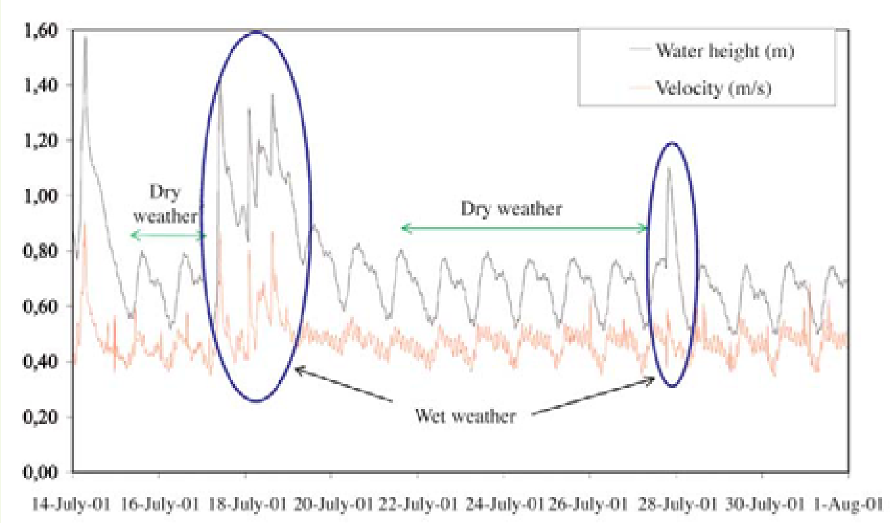
	Height (m)	Velocity ($m \cdot s^{-1}$)
Dry weather: 1st decile	0.50	0.38
Dry weather: 5th decile	0.69	0.46
Dry weather: 9th decile	0.80	0.57

During rainy weather periods, heights and velocities show rapid variations **(Figure 7)**. Given the presence of a storm overflow basin at the *Duchesse Anne* site and another 2 km upstream of the *Jardin des Plantes* site, the notion of a characteristic couple has no real meaning. Local utility operators confirmed the high level of sewer network reactivity to rainfall events in the *Jardin des Plantes* area.

RESULTS

The flow is subcritical turbulent with Reynolds numbers $R_e = \frac{UR_h}{\nu}$ greater than 10^5 and Froude numbers $F_r = \frac{U}{\sqrt{gR_h}}$ lying between 0.25 and 0.50, where R_h represents the hydraulic radius, U the water velocity, g the gravitational acceleration, and ν the kinematic viscosity of water. Jaumouillie

Figure 7
Example of the ranges for heights, velocities and flow rates encountered on the experimental site

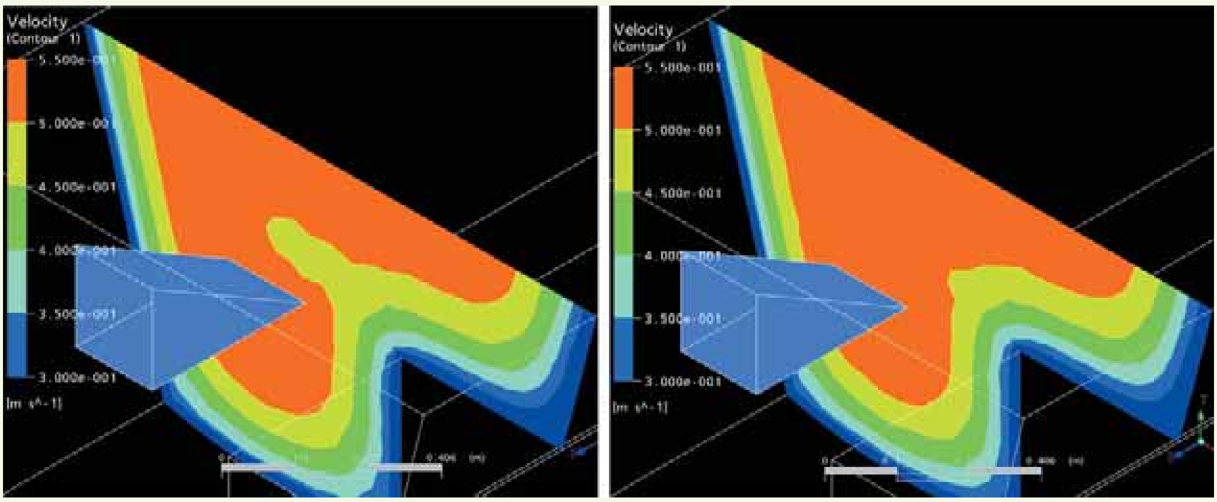


showed **[9]** that the viscosity of wastewater is the same as that of water output from a drinking water supply network.

It was remarked above **(Figure 1)** that the Hydre sampler is indeed intrusive since both the measurement head and vertical support remain in the flow path. The influence of Hydre on the velocity field was studied numerically, leading to the observation **(Figure 8)** that as of a distance 0.10 m upstream of the sensors, this influence becomes negligible. Let's point out that laboratory tests have demonstrated that velocity sensors focused measurements 0.10 m upstream of the actual transducers.

figure 8
Influence of Hydre on the velocity field upstream of the sensors.
a: 0.05 m upstream
b: 0.10 m upstream

a | **b**

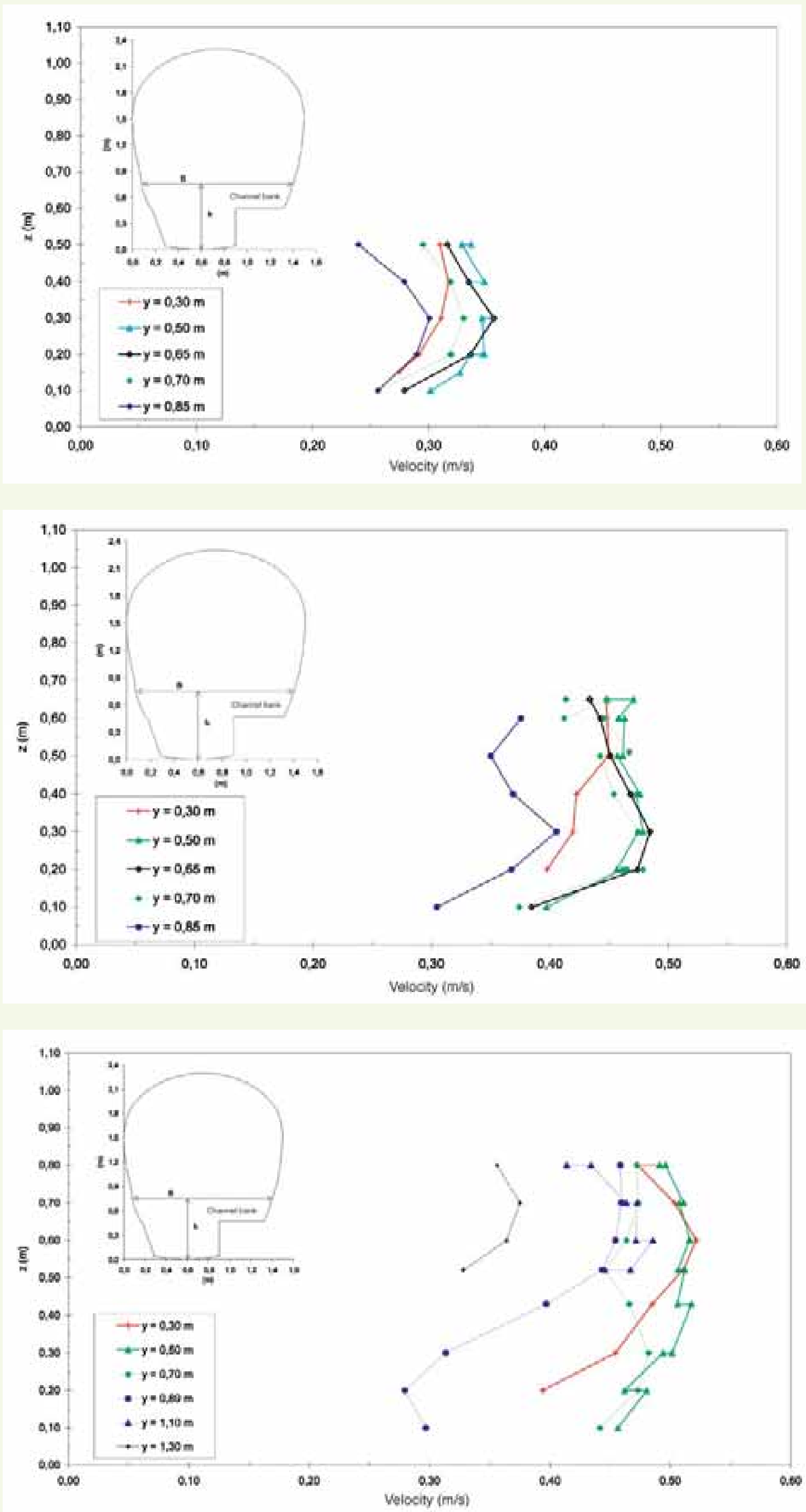


At each point, velocity is measured twice, each measurement being the average of instantaneous velocities recorded over a 10-second interval. This exposure time respects the conditions stipulated in Standard NF EN ISO 748 **[10]** for electromagnetic current meters. Should the deviation between these two measured velocities exceed 0.05 $m \cdot s^{-1}$, this would indicate that sensors need to be cleaned. The wetted section is scanned by vertical profiles that serve to determine the amount of wall friction.

The meteorological situations encountered during a year of operations ranged from very dry weather during summer, with the channel bank still remaining immersed, to heavy rains. Given that measurements are performed in situ and not in the laboratory, it proves impossible to control hydraulic conditions, and this has been reflected by the fact that both velocity and water height changed between the first and last measurements. **Figure 9** displays the vertical profiles measured for various filling rates. **Figures 9a** and **9b** correspond to 2 days of dry weather, while **Figure 9c** shows the profiles obtained during an ordinary rainfall event: a total of 0.003 m of rain fell on

Figure 9
Velocity profiles in the absence of an adjacent storm overflow basin
a: filling rate of 24%
b: filling rate increasing from 28% to 32%
c: filling rate increasing from 44%

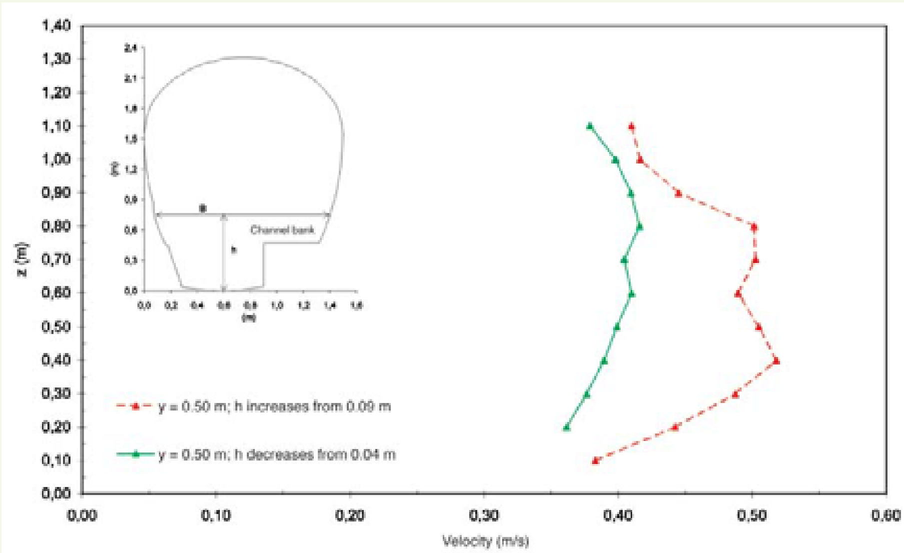
a
b
c



the city of Nantes on this particular day, with storm overflow basins in the vicinity not operating, which would be normal for such an ordinary event. As could be expected under these narrow channel conditions (characterized by the fact that the aspect ratio Ar between free surface width B and maximum water height h_{max} during measurements stays below 5), the maximum velocity occurs beneath the surface. It should be emphasized that flow in these channels is three-dimensional and the profiles do not respect Coles Law. Prudence must therefore be used when applying the requirements of Standard NF EN ISO 748 **[10]**, which serves to calculate average velocity from a known free surface velocity. Near the vertical wall of the channel ledge, the special shape of velocity measurement profiles can be seen above the bank, in addition to the strong transverse velocity gradient due to wall friction **(Figures 9b and 9c)**. Above the bank, the local variations observed are on the order of 0.03 $m \cdot s^{-1}$.

Figure 10 illustrates the difficulty involved in obtaining measurements for heavy rainfall situations. These profiles were generated in a context of storms causing an average precipitation of 0.23 m in Nantes on this particular day. During the first series of measurements, the water rose very quickly (a variation of 0.09 m in 15 min) until reaching the thresholds of overflow basins located nearby. At the same time, wind gusts were observed in addition to strong turbulence in the flow. For the second measurement series, the water height dropped by 0.04 in 20 min, with the pace of measurements being slowed due to the repeated and useless extractions caused by a nozzle obstruction.

Figure 10
Influence of the evolution in water height on velocity profiles during stormy weather



It can also be noted that the (dimensionless) velocity profiles divided by maximum velocity within the section are just about superimposed **(Figure 11)**.

As regards pollutants, each wastewater sample is analyzed twice, in the laboratory according to Standard NF EN 872. These analyses serve to characterize the concentration in particles smaller than $2 \cdot 10^{-3}$ and $125 \cdot 10^{-6}$ m in suspended matter and associated organic matter contents. The precision of these analyses was evaluated at 10 $mg \cdot l^{-1}$. Using this procedure, over 500 results from dry weather concentrations and nearly 200 for rainfall events were generated. **Figure 12** indicates that the concentration in suspended matter tends to remain between 150 and 350 $mg \cdot l^{-1}$, i.e. the same range of concentrations as during dry weather measurements at the *Cordon Bleu* site located 5 km downstream **[7]**. Wet weather concentrations at the *Jardin des Plantes* site however are slightly lower: 66% of concentrations were observed below 200 $mg \cdot l^{-1}$, vs. just 55% during dry weather.

Figure 11
Evolution in dimensionless vertical profiles vs. filling rate
a: at y = 0.50 m
b: at y = 0.89 m

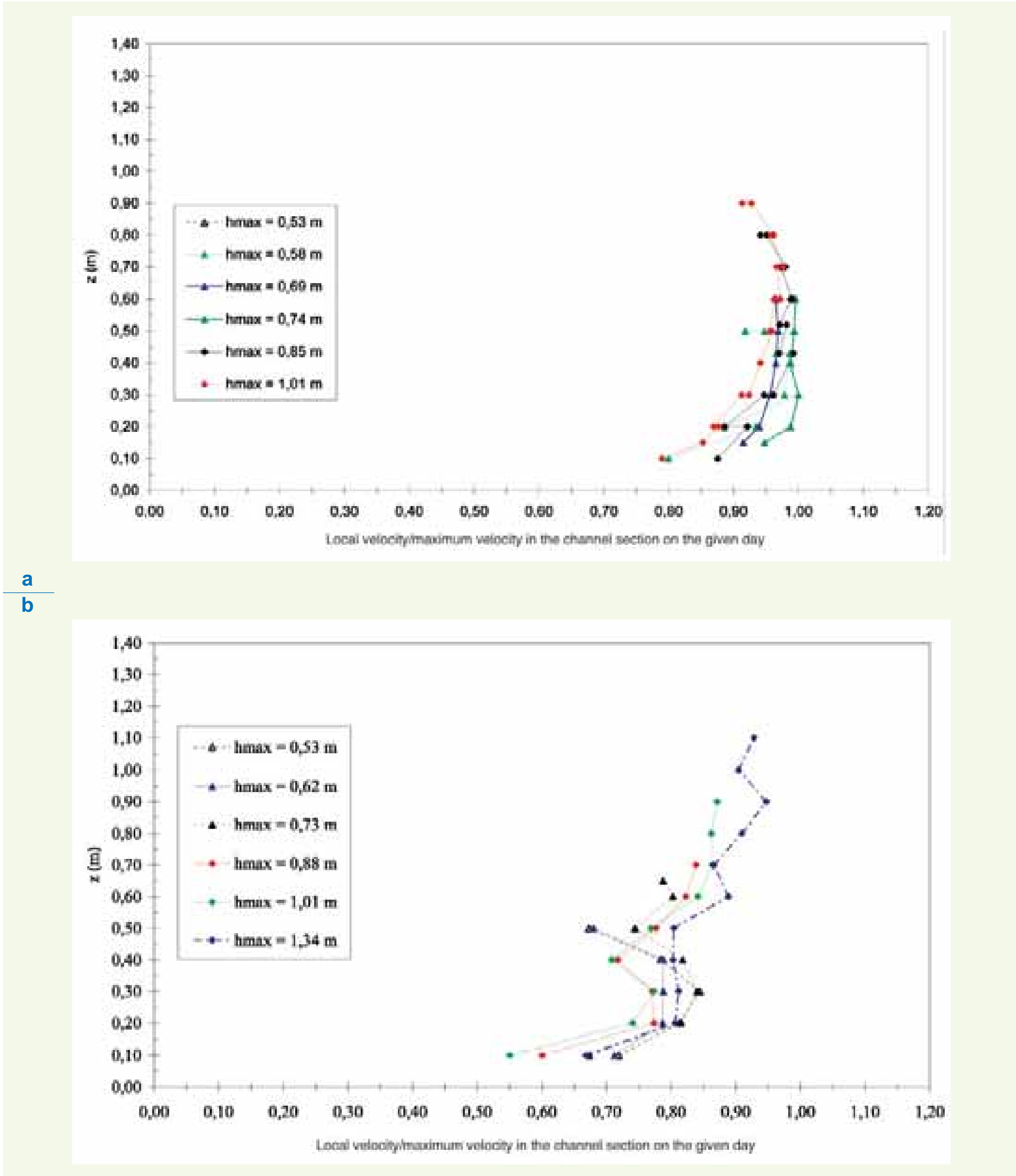
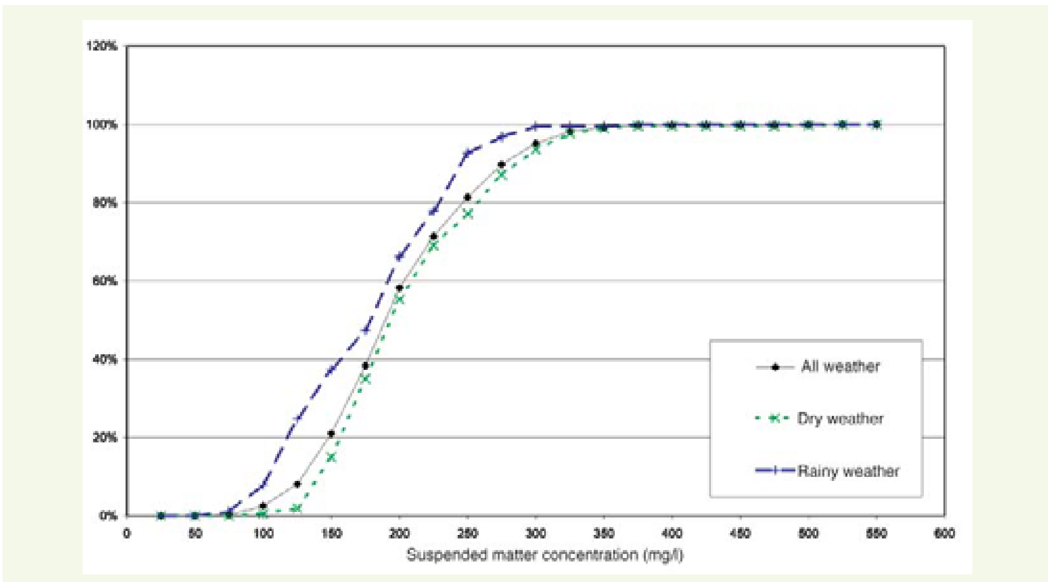


Figure 12
Evolution in concentrations vs. water height in the section

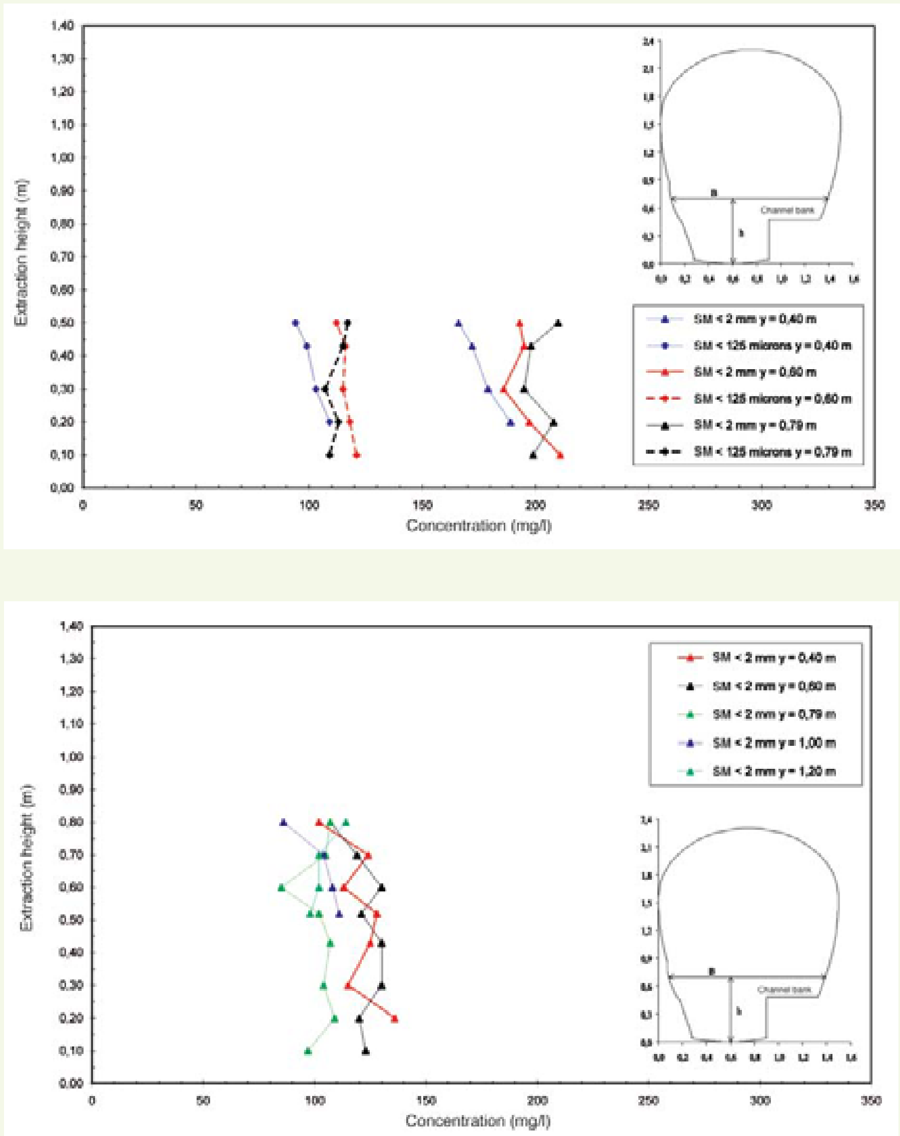


The curves in **Figure 13** reveal examples of dry weather concentration profiles. The existence of vertical fluctuations in local concentrations is observed, yet without any gradient. During a dry weather day however, the average velocity in the wetted section was 0.37 $m \cdot s^{-1}$; a sandy deposit 0.02 m high was observed at the point of sampling and its thickness increases heading upstream to reach 0.04 m 12 m upstream. This finding focused our attention on the notion of vertical concentration gradients, as presented by Wohrle and Brombach in 1991 **[11]**; according to us, the peak observed near the bottom relates to the extraction within the deposit. Let's close by noting that:

– the percentage not passing the 0.002 m diameter sieve remains negligible;
– fine particles constitute on average 58% of all suspended particles during a dry weather day and 67% on a rainy day (rainfall of 0.01 m over the six hours preceding the measurements).

Figure 13
Example of concentration profile
a: dry weather, filling rate of 25%
b: rainy weather, filling rate of 44%

a
b



CONCLUSION

As a means of validating the models used to develop a qualification methodology for measurement sites, a two-dimensional sampler was designed and built for the purpose of measuring velocity and suspended matter fields within a straight section of sewer channel. This set-up, called Hydre, has enabled acquiring field data in various hydraulic contexts.

The experimental results obtained indicate that, for this narrow channel, the maximum velocity lies below the free surface and that (dimensionless) velocity profiles divided by maximum velocity may be superimposed. These findings confirm the observations forwarded by Larrarte and Cottineau **[7]** on the *Cordon Bleu* site. This research has also served to propose a law for vertical velocity profiles **[12]**.

As regards the solids transported in suspension, the absence of vertical concentration gradients was once again noted, even on days when a few centimeters of sedimentary deposit were present. This finding drew our attention to the peaks occasionally observed near the bottom, which for us relates to the extraction within the deposit.

The field measurement campaign will be continued in order to extend the range of results, especially during rainy weather and, in so doing, enable validating numerical results on solids transported.

NOMENCLATURE

$Ar = \frac{B}{h_{max}}$	aspect ratio	
B	free surface width	m
D	maximum channel height	m
$F_r = \frac{U}{\sqrt{gR_h}}$	Froude number	
g	gravitational acceleration	$m \cdot s^{-2}$
h	water height	m
h_{max}	maximum water height	m
R_h	hydraulic radius	m
$R_e = \frac{UR_h}{\nu}$	Reynolds number	
U	water velocity	$m \cdot s^{-1}$
ν	water viscosity	$m^2 \cdot s^{-1}$
y_{max}	maximum channel width	m
z_{max}	channel height at the point of maximum width	m

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